The Economics of Sustained Ocean Observations:

Benefits and Rationale for Public Funding

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Contents

Preface

The National Oceanographic Partnership Program, an organization of Federal agencies, academic groups, and industry, has formulated a plan for an Integrated Sustained Ocean Observing System (ISOOS). ISOOS is to be an integrated ocean observing system that would routinely gather ocean information similar to the information gathered for atmospheric weather forecasting.

The U.S. currently spends substantial funds on these activities, and ISOOS will represent a significant incremental investment on the part of the Federal government. The soundness of this investment will depend on its expected costs and benefits. Therefore, it is important to understand a full range of the economic dimensions of ISOOS.

Accordingly, Mel Briscoe of the Office of Naval Research and NOAA's Stan Wilson asked NOAA's Chief Economist to form a Panel of economic experts to prepare an assessment of the economics of ISOOS by the spring of 2000. The Panel, whose members have all published studies of the benefits from information systems similar to ISOOS, was asked to:

- identify and assess economic sectors and activities that would benefit from ISOOS,
- review and assess the available published estimates of the benefits from existing and similar new systems that depend on ocean observations, and
- assess the rationale and justification for public funding for a system like ISOOS.

A cost-benefit analysis was beyond the scope of our effort, in part because of time and expense, but also because ISOOS costs are not well defined at this point and economists are only now beginning to quantify ISOOS benefits.

Instead, the important policy question for the Panel is whether ISOOS should move forward to authorization and funding based on what we know or can reasonably infer from the full range of benefits expected from ISOOS, both quantitative and qualitative. The Panel's review concluded that ISOOS benefits will significantly exceed costs and that the project should move forward. The Panel also concluded that the network externalities and public-good characteristics of ISOOS argue for Federal support to achieve the full benefits of the system.

Special thanks to members of the Panel and in particular to Tom Teisberg and Hauke Kite-Powell who served as the lead authors. Tom Malone, Worth Nowlin, and Bob Winokur advised the Panel on scientific and technical aspects of ISOOS. Jerry Slaff helped with production.

This is an on-going effort to support the policy process by better understanding the economic dimension of this important national initiative. Comments and suggestions are invited.

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Executive Summary

The National Oceanographic Partnership Program has formulated a plan for an integrated Sustained Ocean Observing System (ISOOS), a comprehensive information network that will contribute significant benefits throughout the nation. This report reviews the economic benefits of ISOOS and the rationale for its support by the Federal government.

ISOOS is a Major Shift in Ocean Observation

The United States has been making significant investments in ocean research, monitoring and forecasting. However, there is little coordination in monitoring and data collection let alone continuity and integrated analysis of historical records. Currently ocean monitoring is fragmented with observations often taken by ships at sea or old lighthouses; while there is satellite data, they are not comprehensive and large expanses of the ocean remain unobserved, by ship or satellite, for substantial periods of time.

ISOOS is a major shift in the approach to ocean observation. By systematically collecting data and integrating hundreds of thousands of measurements from the world's oceans in conjunction with mathematical models, a more sophisticated understanding of ocean-related systems becomes possible. This will improve short-term weather forecasts, seasonal weather forecasts, marine forecasts, ocean statistics, and basic research, thereby producing benefits for people and businesses throughout the US economy.

Rationale for Federal Support of ISOOS

Because ISOOS data will provide benefits across a wide and diverse group of users, ISOOS will create network externalities—the value of the system will be much greater than the sum of the values of the individual parts. However, the direct incentive for any concern (individual or business) to pay for the system is limited to the value of the part of the system that directly benefits that concern. Acting independently, all concerns would therefore under-invest in the development of the system. Moreover, the transaction costs involved in negotiating private cooperative agreements to realize the network externalities of ISOOS are formidable.

The economic benefits of ISOOS will come from the information that is ultimately derived from the systematic collection and analysis of ISOOS data. Information often has the characteristics of a public good. Once produced, information is almost costless to distribute and the total benefits of the information are greatest if the information is made available to any concern that might benefit from it. Also, some information produced by ISOOS may improve public policy decisions that affect everyone in the country (or the world). These benefits simply cannot be limited to those who have paid a share of the costs of the system. In this kind of application, the information from ISOOS is a pure public good.

These network externalities and public good characteristics of ISOOS argue for Federal support in order to achieve the full benefits of this system. But the fact that there is a compelling case for public involvement does not mean that any investment should be made. The investment should be made only if the benefits of the system can be reasonably expected to exceed its costs.

Economic Benefits of ISOOS

The soundness of a Federal investment in ISOOS will depend on its expected costs and benefits. Current Federal support of ocean research is about $600 million a year, some portion of which supports activities likely to become part of ISOOS. Additional costs of implementing ISOOS are expected to grow from about $30 million to $100 million annually. These costs will become better defined as ISOOS requirements are defined in more detail. According to preparatory documents for the 1992 Rio Conference, the project annual operating cost of a fully implemented Global Ocean Observing System, of which ISOOS will be a part, will be approximately $2 billion.

Estimating comprehensive economic benefits from ISOOS is hindered by the lack of direct estimates of the value of ISOOS data for projected applications. However, a review of estimates of economic benefits derived from existing ocean data collection indicates large benefits. Because the scale of benefits now derived from ocean data is large relative to the primary costs of ISOOS, this evidence supports a conclusion that the economic benefits of ISOOS will comfortably exceed its costs.

This report reviews the full range of benefits expected from ISOOS. It also highlights certain benefits derived in seasonal forecasts for agriculture and hydroelectric generation, and in the use of ocean data in coastal management. Seasonal forecasts are one area where good estimates of the value of information exist, while coastal management problems have a tangible impact on the daily lives of millions of Americans who either live near the coast or visit the coast for recreational activities.

In agriculture, many decisions could be improved with a reliable seasonal weather forecast. One recent study found that by incorporating El Niño Southern Oscillation (ENSO) forecasts into planting decisions, farmers in the United States could increase agricultural output and produce benefits to the U.S. economy of $300-400 million per year. Another study estimated that the value to society of ENSO forecasts on corn storage decisions in certain years may be as high as $300 million—or one to two percent of the value of U.S. agricultural production. A third study on the costs and benefits of ENSO forecasts concluded that for agricultural benefits alone, the real internal rate of return for Federal investments in ocean observation for ENSO prediction is between 13 and 26 percent. This range is well in excess of the Office of Management and Budget's (1992) recommended hurdle rate of seven percent.

While precipitation and temperature depend on the ENSO phase, they also depend on two other less-understood phenomena—the North Atlantic Oscillation, and the Pacific Decadal Oscillation. ISOOS would help improve understanding of these two phenomena; if this led to better predictive capabilities, substantial improvements in seasonal forecasts would follow. This is an instance of direct evidence (in contrast to inferred evidence) that the incremental benefits of ISOOS would be substantial, and presumably of the same order of magnitude as those of the ENSO forecasts.

Because hydroelectric power generation is significantly affected by seasonal precipitation that differs across ENSO phases, an ENSO forecast should have significant value in managing water use for electricity production. Moreover, the benefits of seasonal forecasts for hydroelectric production, like those for agriculture, will increase if the North Atlantic Oscillation and the Pacific Decadal Oscillation can be forecast reliably.

Protective management of the U.S. coastal zones requires accurate information about contaminant flows in order to develop policy regarding wastewater treatment and disposal, trash disposal, airborne pollution control, beach closures, and public health restrictions on seafood consumption. For example, a new outfall pipe for treated sewage from the metropolitan Boston area is designed to shift waste inputs from Boston Harbor to Massachusetts Bay. However, the prospect of nutrient loading in the Bay has raised concerns about possible effects on marine life and environmental conditions along the heavily used beaches of Cape Cod Bay. To address these concerns, extensive ocean monitoring is necessary to characterize marine environmental conditions in Massachusetts Bay and Cape Cod Bay prior to and after the utilization of the new outfall. ISOOS would provide this kind of monitoring capability and help to predict or assess the consequences of alternative waste disposal decisions.

Coastal management also includes the protection of beaches and public safety in beach use. Millions of Americans use coastal beaches throughout the year as a major source of recreation, and thousands of jobs in almost every coastal state depend on access to safe, clean beaches. Numbers of threats to these beaches are directly connected to the movement of ocean waters. In California and much of the east, combined sewer overflows can temporarily close beaches when high levels of untreated sewage are pumped into the sea following storms. Oil spills are another threat that can damage beaches for months or years. In each of these cases, a thorough understanding of nearshore ocean circulation, which is in turn influenced by larger ocean patterns, is essential to knowing when and where the pollutants will go, and for how long they will degrade beaches. In the case of oil spills, deployment of clean up equipment and strategies depends heavily on oceanographic models that in turn rely on the kind of ocean circulation data that does not exist but that ISOOS will provide. While ocean data cannot eliminate beach closures or prevent oil spills, reliable data, analysis and interpretation can help reduce unnecessary precautionary beach closures, reduce the duration of closures, and minimize the potential damages from oil spills. Though direct estimates of the value of ocean data are not available, there is good reason to believe that this value is significant.

Beyond seasonal forecasts and coastal management, there is strong evidence that the information from ISOOS will produce significant economic benefits for a wide range of additional activities. They include the prevention of damage and deaths from storms, the ensuring of safety in design of offshore oil platforms, the facilitating of Naval operations, and the monitoring and understanding the processes of global climate change. Important values are at stake in most of these activities. The contribution to the U.S. economy of industries and other activities that have been identified as likely beneficiaries of ISOOS products is on the order of one trillion dollars. Given the scale and range of the affected economic activities, it is reasonable to conclude that the benefits of ISOOS will significantly exceed its costs.

The Integrated Sustained Ocean Observing System

Overview

The National Oceanographic Partnership Program (NOPP 1999) has formulated a plan for an Integrated, Sustained Ocean Observing System (ISOOS). ISOOS is to be a national ocean information system similar to the existing national weather information system.

While numerous U.S. research organizations, government agencies, and commercial interests collect ocean data, most of this data collection is carried out to satisfy the narrow requirements of a particular research program or management decision. A national strategy does not exist for sustained collection of long time series data and comprehensive management of these data to ensure their long-term usefulness.

ISOOS will integrate "disparate observational systems and data sets to maximize their utility for many users and purposes" (NOPP 1999), and will move U.S. ocean observation from what is now largely an *ad hoc* approach to a coordinated, sustained activity. This means that ISOOS will ensure that existing and new ocean observation efforts are integrated by centralizing the data management function. Its implementation will require investments in infrastructure (networks and data management systems) and ongoing support for new and existing observation systems in the open and coastal ocean. The Appendix provides a detailed listing of the elements of the NOPP's plan for ISOOS.

The data that ISOOS makes available will serve three key activities--modeling and forecasting of climate, weather, and ocean conditions, monitoring and current conditions reports, and basic research.

The data that ISOOS makes available will serve three key activities:

- **Modeling and forecasting of climate, weather, and ocean conditions:** This includes short term land weather forecasts, marine weather forecasts, and long term (seasonal to interannual) forecasts such as those now made of the El Niño Southern Oscillation (ENSO). Models vary in scale from global to local.
- **Monitoring and current conditions reports:** This includes local water quality measurements, monitoring of ecosystems health, and reports on water levels,

currents, and waves ("nowcasts"). It also includes global environmental monitoring related to climate change and the behavior of major ocean systems such as the Gulf Stream.

- **Basic research:** Research in the fields of oceanography, meteorology, and climatology will make use of ISOOS data, improving our understanding of the oceans' role in the world's ecosystems. Improved historical ocean statistics will be of particular importance.

ISOOS will serve the development of new and improved models for weather prediction, more complete and useful reports on marine conditions, and more rapid advances in ocean related research. These improvements will provide economic benefits to a wide range of users of information derived from ocean data, and they will help achieve the overarching goals of the ISOOS system, which are to help:

- detect and forecast oceanic components of climate variability,
- facilitate safe and efficient marine operations,
- ensure national security,
- manage living resources for sustainable use,
- preserve health and restore degraded marine ecosystems,
- mitigate natural hazards, and
- ensure public health.

The Costs and Benefits of ISOOS

ISOOS is the U.S. contribution to the Global Ocean Observing System (GOOS). Preparatory documents for the 1992 Rio Conference suggested that the annual operating cost of a fully implemented Global Ocean Observing System would be around $2 billion. $1.3 billion of this represents the cost of eight oceanographic satellites. Of the remaining $700 million, more than 60 percent is required for open ocean monitoring (outside nations' exclusive economic zones, or EEZs), while the balance would fund monitoring within EEZs. The annual operating costs of World Weather Watch are also about $2 billion.

The cost of ISOOS is estimated to be roughly one third of the GOOS total. The Federal government currently spends about $600 million per year for ocean research. Some portion of this funding already supports activities that likely will become parts of ISOOS. The estimated additional cost of implementing ISOOS is expected to grow from $30 million to a "steady state" of about $100 million per year (NOPP/ORAP 1999). These costs will become better defined as ISOOS requirements are defined in more detail.

Other countries have participated in GOOS planning and have committed substantial resources to its implementation. For example, Japan has committed $10 million in FY2000 for its portion of a global network of profiling floats.

The immediate product of ISOOS will be ocean observations—data on the physical, chemical, and biological characteristics of marine waters and the ocean/atmosphere interface. These data will be an input to a wide range of monitoring, modeling, and research activities. Economic benefits will derive from the output of these activities—in applications such as marine conditions reports and weather and climate forecasts, and improved understanding of ocean phenomena.

Figure 1 illustrates these linkages from data to applications and indicates the costs and benefits relevant to an economic assessment of ISOOS. The columns in this diagram represent the existing ocean data systems and the improved systems expected with ISOOS. The first row of the diagram represents the availability of raw ocean observational data for the two systems. The second row represents products, such as seasonal weather forecasts, that are supported by ocean data. The third row represents applications of these products, such as using a seasonal weather forecasts to make crop choices in agriculture.

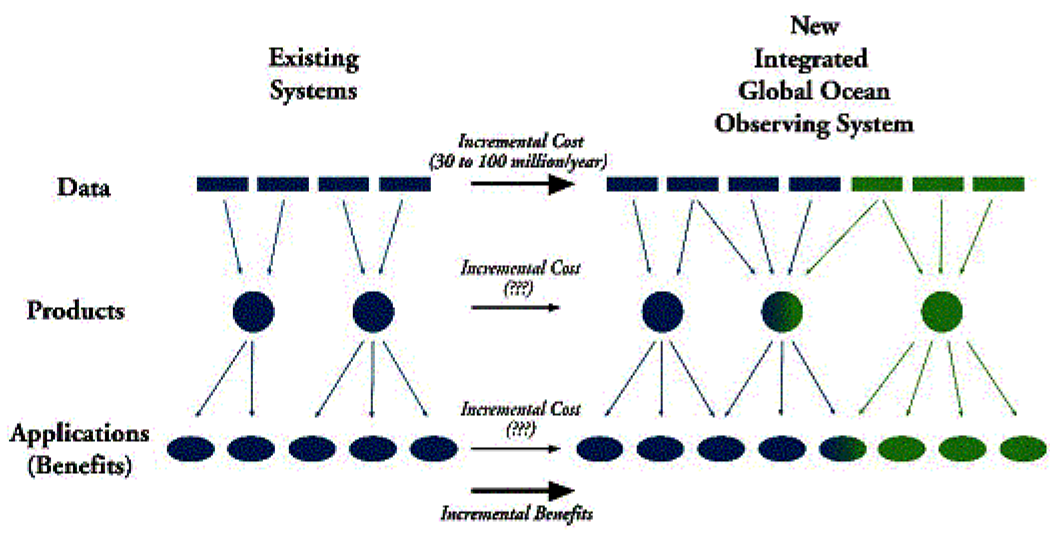

Figure 1: U.S. ocean observation today and with ISOOS.

As the diagram suggests, ISOOS will generate new data not now available, and this in turn will lead to new products, and perhaps to better support for existing products. These new and/or enhanced existing products will find applications, both new and existing. The benefit of ISOOS is an incremental benefit of moving from the applications in column one to those in column two. The costs of ISOOS are estimated to be $30 million rising to $100 million per year to move from existing ocean data to the expanded and improved ocean data expected with ISOOS.[1] These costs are indicated by arrows in the diagram, as are the incremental benefits of ISOOS.

ISOOS will improve existing applications of ocean data and make possible new applications to create informational values that could not be realized without integrated and sustained ocean observations.

The U.S. has already made significant investments in parts of an ocean observing system, so the question is whether the incremental investment requested now will be worth the increment of benefits to be gained. The economic principle of diminishing marginal returns raises the possibility that the increment to be gained would not be as great as the cost. However, in the case of ISOOS, this does not seem likely in the foreseeable future.

The reason is that ISOOS is more appropriately thought of as a new information system rather than as a marginal improvement in an existing system. The current ocean observation system exists in scattered pieces. Observations are often taken from “platforms of convenience” which may be ships at sea or old lighthouses. The former provide observations that are not sustained, while the latter take place at locations that may or may not be important from an oceanographic perspective. Data from many sources are rarely brought together. And large expanses of the ocean remain unobserved for substantial periods of time.

In contrast, ISOOS would organize ocean data collection to ensure broad and sustained data collection and distribution. This will improve existing applications of ocean data and make possible new applications to create informational values that could not be realized without integrated and sustained ocean observations.

[1]There are additional private and public costs associated with moving from ISOOS data to products and economic benefits. These include the additional (unknown) costs of creating new or improving existing products with the data expected from ISOOS, and the additional unknown, but largely private, adoption costs of applying these new products to produce benefits.

Though it is common to assume that better information must have economic value,[2] such information must affect economic wealth, income, or well-being. Moreover, in most cases it must also be true that people can use the information to make better decisions that increase wealth, income, or well-being.[3]

Procedurally, quantifying the value for information requires two numbers. First is the expected benefit or cost that results without the information, and second is the expected benefit or cost that results with the information. The difference between these two numbers represents the expected value of the information. For each case (information present or information absent), expected benefits or costs are calculated assuming that the actions taken are the optimal actions to take, given the unknowns that exist for that particular case.

A procedure like that described above underlies the quantitative value of information estimates that are presented later in this document. In many instances, however, we cannot present quantitative estimates of information value because such estimates have not been made. In these cases, we present qualitative evidence regarding the magnitude of informational value. Qualitatively, information value is expected to be high when the information would be used in an activity of significant scale or importance and where there are identifiable actions that could be taken in response to information and that would significantly improve income, wealth, or well-being.[4]

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[2]Better information should never be a bad thing, since information can always be ignored. However, there is a possible exception to this—the "ignorance is bliss" exception. For example, if you could learn the exact date of your death, but you could do nothing to change it, your enjoyment of what remains of your life might be diminished by knowledge of your date of death.

[3]In some special situations, information may have value even though no actions are taken. For example, no actions would be taken as a result of obtaining a more precise estimate of the age of the universe, but nevertheless this information might have value to people simply because it is interesting.

[4]Many ISOOS products result in economic benefits in important so-called "non-market" activities such as coastal recreation or ecosystem protection. Because these activities do not generate directly observable prices and quantities, economists employ indirect and direct techniques, such as travel-cost models, to measure people's willingness-to-pay for improvements in these activities resulting from better forecasts. This makes it possible to value improved forecasts for both market and non-market activities. See Braden and Kolstad (1991).

Once operational, ISOOS will provide data to oceanographers, meteorologists, climatologists, and other scientists working on the oceans and atmosphere to create a variety of improved information. Some of these results will be in the public scientific domain, but if the experience over the past three decades with weather data is a guide, much will also be generated and sold in private markets. Once the costs of the basic data collection and storage are covered, the private sector will find ways to add value to the data to provide custom products and services that can be priced and sold. This will result in the creation of new firms, new employment, and perhaps new industries built around using, enhancing and selling information derived from ISOOS.

Ideally, we would estimate all the incremental benefits of ISOOS, as well as all of the incremental costs of ISOOS, and calculate a benefit/cost ratio or a net benefits number. This report presents what is known or might reasonably be presumed about the benefits that are now derived from the kinds of data that ISOOS will provide.

How many new firms and jobs, and their location, cannot be predicted at this time. But it is likely that most of the jobs will cluster around major research institutions involved in the study of ocean, atmosphere, and hydrology. Much of this activity will take place in coastal states, but centers for the study of these fields are located throughout the United States, and thus the new firms and jobs can be expected throughout the country.

Ideally, we would estimate all the incremental benefits of ISOOS, as well as all of the incremental costs of ISOOS, and calculate a benefit/cost ratio or a net benefits number (see Brown [1999]). However, making these kinds of estimates is well beyond the scope of this Report. Costs of an emerging ISOOS are not well defined and economists have just begun to quantify the economic benefits of ISOOS-related products. What this report does do is to present what is known or might reasonably be presumed about the benefits that are now derived from the kinds of data that ISOOS will provide. While these benefits are based on existing systems rather than the incremental benefits expected from ISOOS, they indicate the scale of benefits now derived from ocean data and suggest the possible magnitude of the incremental benefits that might be derived from expanded, more complete, or more accessible ocean data that ISOOS would provide.

The following section examines the rationale for public funding of ISOOS. *Highlighted Benefits from ISOOS Data* presents a couple of particularly clear examples of benefits that might be anticipated from ISOOS, while *Additional Benefits from Ocean Data* discusses a wide range of additional benefits that may be obtained from ISOOS. *Benefits from Basic Research* discusses the value of ISOOS' contribution to basic research. *On-going and Future Research* briefly notes present research related to ISOOS, and the last section provides a short conclusion.

Economic Considerations in Valuing ISOOS

Network Externalities and Public Goods

The proposition that ISOOS is likely to be a worthwhile economic investment is based in part on three key features that determine its value: ISOOS will be integrated, sustained, and comprehensive (or "global," in the context of GOOS). A system of ocean observations that has these three characteristics will have value many times that of one that lacks any of these features.

To understand why, it is only necessary to consider such a system that already exists and which the U.S. government already supports: atmospheric observations for weather. Anyone with a thermometer, a barometer, and a wind gauge can take the measurements needed to know what is happening in the weather at that particular spot. But if everyone who took these measurements simply watched their own instruments, the amount of weather information available to society would be very limited. If the thousands of individual observations are brought together (integrated), a complete picture of the weather systems is possible. Weather maps can be made. If a database of historical observations can be maintained (sustained), it is possible to develop statistical models of the atmosphere from which weather forecasts can be made. Since the atmosphere moves in large scale around the world (global), only a complete set of observations around the world can provide a complete picture and reliable forecasts.

ISOOS will be integrated, sustained, and comprehensive. A system of ocean observations that has these three characteristics will have value many times that of one that lacks any of these features.

Thus the value of an integrated, sustained, and global ocean observation system will derive from its ability to bring together currently scattered observations, to create a data base from which historical trends can be measured and forecasts developed, and to extend the reach of observations to all corners of the ocean where important changes may occur. As with the weather, once such a system is created the value will be much greater than the sum of the individual observations, which is to say, ISOOS creates network externalities.

But the existence of network externalities creates a paradox. While the value of the system is many times that of the value of its parts, there is no real incentive for any one individual (or company) to pay for the creation of the system. This is because it is difficult for any one individual to obtain compensation for the external benefits that would result from creating the system.

But the existence of network externalities creates a paradox. While the value of the system is many times that of the value of its parts, there is no real incentive for any one individual (or company) to pay for the creation of the system.

The collection of ocean observation data on the scale necessary for a functioning ISOOS will benefit so many different users that it will be nearly impossible to figure out what any one should be willing to pay as their share of the costs. Moreover, once the system is in place, there will be a strong incentive for any individual user not to pay his or her share of the costs but to "free ride" on the fact that the system already exists. Of course if everyone followed this logic, the system could not exist if individual contributions were relied on as the exclusive means of paying for data collection. If an arbitrary price for the data is enforced, some potential users will not be willing to pay this price, and the benefits they would derive from the data will not be realized, even when such benefits would exceed the minimal costs of distributing the data.

The economic benefits of ISOOS will come from the information that is ultimately derived from ISOOS observations. Information has some of the characteristics of a public good. Once produced, information is almost costless to distribute and the total benefits of the information are greatest if the information is made available to anyone who might benefit from it.

In addition, some of the potential benefits from ISOOS information are likely to be derived from its use in determining government policy that affects virtually everyone in the United States (and people outside the US, as well). For example, some information obtained from ISOOS could influence policy decisions with respect to assessing worldwide emissions of carbon dioxide. In such policy applications, ISOOS information is close to a pure public good like national defense.

In addition, some of the potential benefits from ISOOS information are likely to be derived from its use in determining government policy that affects virtually everyone in the United States

Uncertainty and Transactions Costs

In addition to these "public good" characteristics, ISOOS presents another economic challenge that makes it particularly appropriate for the government to pay the costs (assuming as we discuss below that anticipated benefits will likely exceed anticipated costs). Many goods and services have some of the characteristics of a public good, and are provided by both the public and private sectors. There are, for example, both public and private roads. But in these cases, a great deal of information is known about how the good or service will be used and who will use it. ISOOS, on the other hand, is like investing in a road whose links to other roads are unknown at the time of the investment and whose major payback will only come when all roads are linked to every other road. In such cases, investment returns are both uncertain and dependent on others' actions; this makes it difficult to privately negotiate a solution that produces a road system generating anything close to the maximum possible net benefit.

To illustrate this in an ocean context, consider the problem facing an oil company which has a one billion dollar oil platform to be placed in the Gulf of Mexico. Placement of the platform must be done precisely and must take place when there is a certainty of an extended period of calm weather and water. The oil company would be willing to place ocean current monitors in the Gulf of Mexico to be sure they understood the oceanographic conditions in which they will operate.

But they also need to have accurate weather information over an extended period of time, and long-term weather forecasts for the Gulf depend in part on changes in the ocean temperature in the Pacific Ocean. Again, the oil company might be willing to fund ocean observation stations in the Pacific, but where? In order to be assured that all of the complex interactions of the ocean and atmosphere in the Pacific that will influence the extended weather of the Gulf of Mexico are captured in order to provide a reliable enough forecast, the oil company would have to pay for an ocean observation system that was many times the size (in both geographic extent and time) that it actually needed. Moreover, even if they were willing to make that investment, once they had placed their platform, they would probably dismantle the entire system, since they could not continue the system profitably. Here the value of the information to be gained from investing in the Pacific ocean observation system, however large the private investment at stake, cannot be determined without making the investment itself, since we do not have a complete enough understanding of the ocean to know where to put the monitors.

The uncertainty surrounding the value of the individual parts of ISOOS makes it difficult for individuals to negotiate a collective solution that would maximize the overall benefits derived. As a result, individuals would only invest in those parts that are of direct benefit to them, and the overall system benefits would not be realized. Worse still, the benefits that might motivate an individual to fund some data collection may be transitory, with the result that the observations generated by private investments alone will not be sustained.

Together, these characteristics of a public good, network externalities, and the uncertainty of the value of the individual parts present a strong case that the government must fund the collection and analysis of the data in order to achieve the full benefits of an integrated, sustained, and global ocean observation system. But the fact that there is a compelling case for public involvement does not mean that any investment should be made. Only if the investment in the system can be reasonably expected to be economically sound should it be made. That is the question to which we now turn.

Together, these characteristics of a public good—network externalities, and the uncertainty of the value of the individual parts—present a strong case that the government must fund the collection and analysis of the data.

Soundness of the ISOOS Investment

Without adequate incentives for the private sector to make this large an investment in ISOOS, it is left to the government to decide whether to make the investment. That decision rests on a determination that all of the various individual benefits from such a system will cumulatively outweigh the costs.[5] Unfortunately, the very characteristics that make it necessary for the government to make the investment also make it difficult to know what the precise economic value of such a system is in order to make this comparison (see Brown [1999] for a discussion of approaches to valuing oceanographic activities). It would clearly be desirable to have such information at hand when making the decision, but that is not possible in the time frame available.

Fortunately, it is also not necessary to know the value of the economic benefits to the last dollar before making a decision. Even without precise information, much can be said about the likely magnitude of the economic benefits of such a system at this stage, and what is known is enough to persuade us that the investment in ISOOS, though large, is also sound. There are five reasons why this is so.

- ISOOS represents a major conceptual shift in moving from scattered, partial ocean observing efforts to an integrated, sustained, global observing system; ISOOS is qualitatively different from what now exists.

[5]A comparison of total benefits and total costs ignores issues concerning the distribution of benefits and costs. Some segments of the US economy might be worse off as a result of implementing ISOOS. However, it is not reasonable to insist that every policy be designed so that anyone harmed by that policy is compensated for the harm. Rather, policies are judged on the basis of total benefits compared to total costs, and other policy instruments (notably the tax system) are used to make compensating adjustments in the overall distribution of income within the country.

- There are potential economic development effects to the U.S. economy and to regions within the U.S. which will add modestly to the overall economic benefits but which could benefit parts of the U.S. with new jobs and industries.

- Studies of the economic benefits from recent, though limited, expansions in ocean observation have shown returns well in excess of costs.

- There is a long list of potential beneficiaries beyond those already studied from such a system whose individual benefits cannot yet be measured but which cumulatively will be substantial.

- It has been shown repeatedly that investments in basic research of the kind facilitated by ISOOS are repaid many times over in resulting economic growth.

Even without precise information, much can be said about the likely magnitude of the economic benefits of such a system, and what is known is enough to persuade us that the investment in ISOOS, though large, is also sound.

The first two points were made above in *The Costs and Benefits of ISOOS;* the last three are discussed in detail in the following three sections of this document.

Highlighted Benefits from ISOOS Data

The ocean data that ISOOS is to deliver will find applications across a large number of economic activities. The section *Additional Benefits from Ocean Data* following discusses a wide range of these applications and what we know about economic benefits of improved information for these activities. In the present section, we choose to focus on just two applications of ocean data—the use of ocean data in seasonal forecasts for agriculture and hydroelectric generation, and the use of ocean data in coastal management. We focus on seasonal forecasts because they have value in a wide range of economic sectors and because this is the one area where at least a few good economy-wide estimates of the value of information have been produced. We focus on coastal management because coastal management problems have a very tangible impact on the daily lives of millions of Americans who either live near the coast or visit the coast for recreational activities.

Economic Benefits from Seasonal forecasts

Ocean data have played a key role in the recent success of seasonal weather forecasting based on the El Niño Southern Oscillation (ENSO) phenomenon. Present ENSO forecasts already generate considerable value in economic activities such as agriculture (see section below). Data from ISOOS should improve on this success by giving weather forecasters the ability to predict the North Atlantic Oscillation (NAO) and the Pacific Decadal Oscillation. Like ENSO, these phenomena affect weather in important ways (see Figure 3 below). Unlike ENSO, these effects are not yet fully understood. ISOOS will help fill these knowledge gaps and thereby enable us to improve seasonal weather forecasts and their value to a wide range of economic activities. Nicholls (1996) discusses such values for sectors diverse as energy, manufacturing, water supply, retailing, and transportation. All these sectors have the flexibility to respond to improved climate forecasts. Agriculture and hydroelectric generation are two particularly important climate sensitive sectors.

Agriculture

Many agriculture decisions will be improved with more reliable weather forecasts. Different crops have different water requirements, temperature sensitivities, and growing seasons. Thus, crop choice is a key decision that is sensitive to a weather forecast. In addition, for any given crop, there may be decisions about the timing of planting and harvesting and methods of fertilization and pest control that might be improved with a better weather forecast.

Since the 1940s, scientists have been interested in the socioeconomic use and value of weather and climate forecasts (see GCOS 1995; Mjelde, Hill, and Grifiths 1998). Current forecasts are actively sought by the public, and previous studies show that the adoption and use of weather/climate forecasts will increase society's overall welfare. The majority of these studies have examined the decision-maker level, (*e.g.,* the farm level in specific regions) and show increases in net benefits. For instance, costs could be reduced by nearly $500,000 per year if 50 percent of cotton farmers in Missouri used agroclimate data to eliminate replanting. In Nebraska and Canada, climate information could reduce the need for irrigation enough to save $100,000 per season (Nicholls 1996).

Incorporating NOAA's ENSO forecasts into planting decisions, farmers in the United States could increase agricultural output and produce benefits to the U.S. economy of up to $300 million per year of the forecast.

Recent studies have focused on the value of climate forecasts across entire industries such as agriculture (see column five of table two). One (Solow *et al.* 1998) found that by incorporating NOAA's ENSO forecasts into planting decisions, farmers in the United States could increase agricultural output and produce benefits to the U.S. economy of up to $300 million per year, depending on the accuracy of the forecast. Another study, which factors in uncertainty about ENSO phase strength, grain storage, and effects in the rest of the world raises this value to $400 million (Chen and McCarl 2000). At the next stage of the production/consumption process, McNew (1999) has estimated that the value to society of ENSO forecasts on corn storage decisions in certain years may be as high as $300 million. Since these latter two estimates may involve some double counting, they may be thought of as an upper bound estimate of the annual value of ENSO forecasts—one or two percent of the value of agriculture production in the United States.

ENSO has a clear effect on U.S. weather, but other oscillations also play a role.

Sassone and Weiher (1999) analyzed the Federal costs of developing and operating the TOGA ocean observing system that has led to improved ENSO forecasts, and compared them to the economy-wide benefits in U.S. agriculture from the Solow study. Under various assumptions of forecast accuracy and farmer's acceptance of the forecast, they estimated the real annual rate of return (internal) for these investments to be between 13 and 26 percent. These returns compare quite favorably with the Office of Management and Budget's (1992) guidelines that call for a minimum rate of return of seven percent before considering taxpayer funding for a public project.

ENSO has a clear effect on U.S. weather, but other oscillations also play a role. Both the Pacific and the North Atlantic exhibit decadal oscillations in sea level (air) pressure. These phenomena are not yet well understood; we do not know what causes them or how to predict them. However, they appear to have a dramatic effect on weather in Europe and in the United States. During the 1950s and ’60s, the North Atlantic Oscillation (NAO) Index (see Figure two) was mostly negative, indicating an easterly flow of air across the North Atlantic, and contributing to colder, snowier

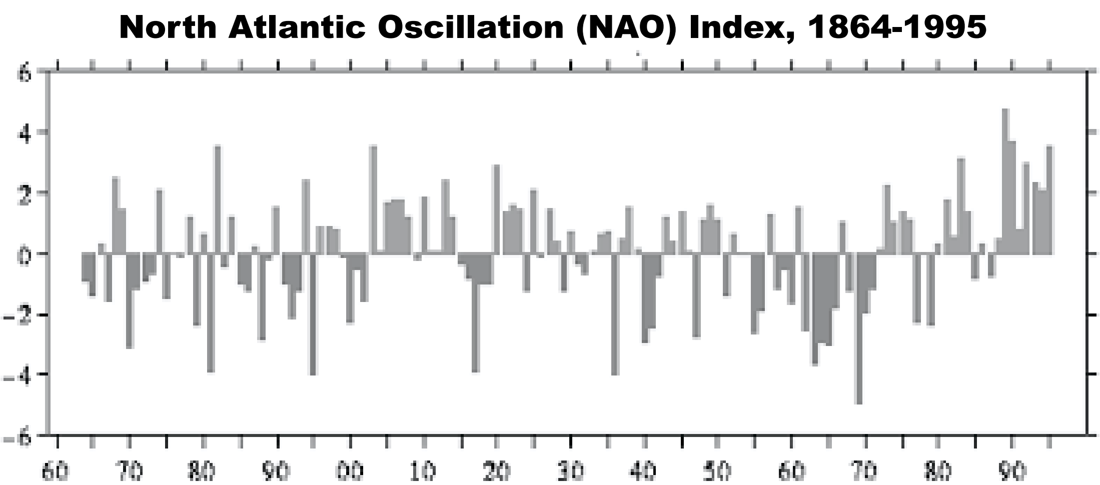

Figure 2: North Atlantic Oscillation (NAO) index.

winters in the eastern United States. More recently, the NAO Index has been positive, with correspondingly milder winters. NAO has also been linked to hurricane activity.

Improved ocean observation is the key to better understanding of NAO and other oscillations; and if we can predict them, we can expect significantly better long-term weather forecasts. Figure 3 shows how the predictability of winter precipitation and surface air temperature over the United States improves when additional ocean phenomena are considered. The numbers in the figure are the correlation coefficients between historical precipitation/surface air temperature and the noted oscillation indices. When squared, these numbers represent the percentage of wintertime climate variability that is potentially predictable using these indices. Thus, the predictability in brown areas is 36 percent or more, while white areas have little or no predictability.

Improved ocean observation is the key to better understanding of NAO and other oscillations; and if we can predict them, we can expect significantly better long-term weather forecasts

We are today at the top of the figure, able to predict ENSO with some certainty. The resulting benefits to agriculture and other activities have proven substantial. As

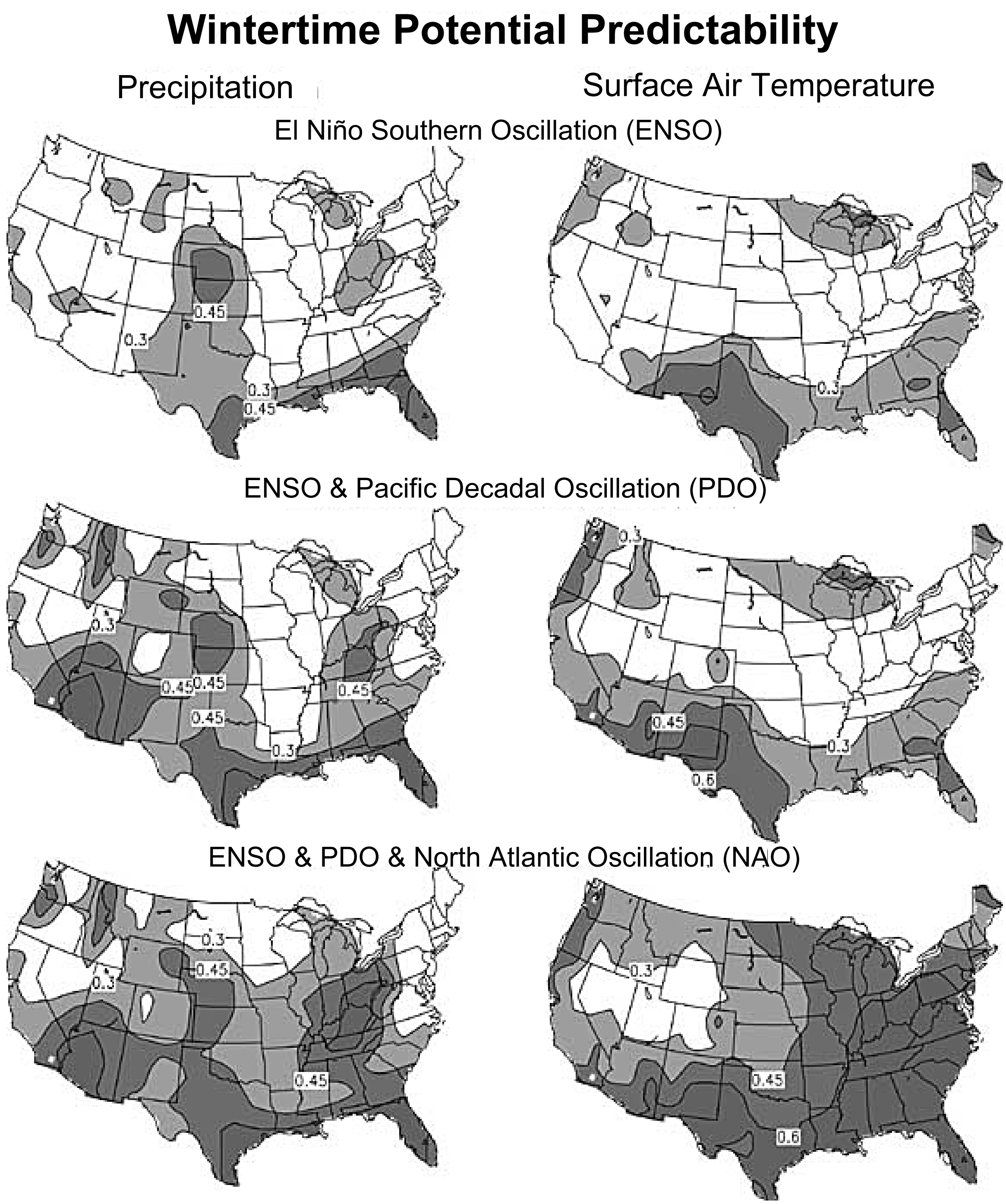

Figure 3: Effect of ENSO, PDO, and NAO on U.S. weather predictability.

we improve our understanding and prediction of NAO and the Pacific Decadal Oscillation, we will move toward the maps in the bottom part of the figure, with significantly greater predictability over more parts of the country. This should produce dramatic improvements in long-term forecast accuracy and significant additional economic benefits. ISOOS and GOOS are critical to the improved understanding and prediction of the NAO and Pacific Decadal Oscillation, and in turn to realizing these improvements in predictability and the associated benefits.

Hydroelectric Generation

Electricity generated from water power, though a relatively small component of total US electric production, is economically important, especially in certain regions of the country. The total value of hydroelectric power production in the United States in 1998 was approximately $20 billion.

Hydroelectric power is inexpensive to produce, once the capital stock is in place. Thus, whenever possible, electric generating authorities would prefer to use hydroelectric power instead of more expensive oil, gas, or coal fired generation facilities. Nature, however, provides the water to produce hydroelectric power, and it does so in somewhat unpredictable volumes. Moreover, there are often other competing uses for water, such as agricultural irrigation, recreation, and ecosystem maintenance. For these reasons, the use of water for hydroelectric power generation is usually carefully controlled so that other water uses are not compromised.

There is a demonstrable economic value of improved information in the operation of hydroelectric generating facilities.

It is clear that reliable forecasts of precipitation would affect decisions about the use of hydroelectric generation capacity. For example, if an upcoming wet season is reliably predicted to be wetter than normal, lower water reserves might be carried into the wet season, and higher water use might be appropriate in the early weeks of a wet season. The converse would be true if an upcoming wet season is reliably predicted to be dryer than normal. Thus, there is a demonstrable economic value of improved information in the operation of hydroelectric generating facilities.

For example, Figure 4 *(next page)* shows average monthly flows for a typical large reservoir operated by the Tennessee Valley Authority from 1948 to 1994. The curves reflect average flows under the three standard ENSO conditions. Note especially the dramatically lower flows (associated with reduced precipitation) during El Niño winters. If forecast accurately, this kind of information is of great value to reservoir managers: they can draw down reservoirs more freely during summer and fall, for example, if a La Niña winter is expected.

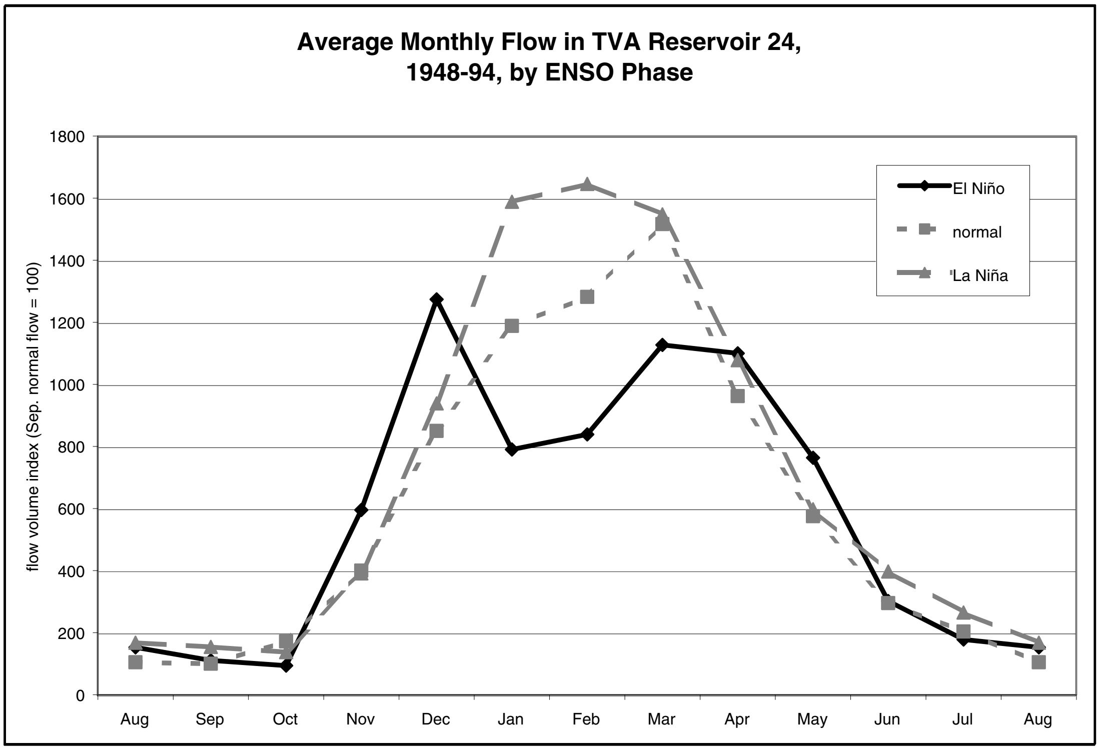

Figure 4: TVA reservoir flow index.

Coastal Management

Coastal zone managers and others concerned with marine water quality and the health of marine ecosystems need information about contaminant flows and stocks in the marine environment. These contaminants can enter the ocean either from discharges directly into the ocean or waterways emptying into the ocean, or from the air. Information about contaminants is needed to set policy regarding wastewater treatment and disposal, trash disposal, airborne pollution control, beach closures, and public health restrictions on seafood consumption. Two examples of potential benefits of ISOOS data relate to sewage waste disposal and beach recreation.

Massachusetts Bay Sewage Outfall Effects

The new outfall pipe for treated sewage from the metropolitan Boston area is designed to shift waste inputs from Boston Harbor to Massachusetts Bay. The prospect of nutrient loading in the Bay has raised concerns about possible effects on marine life and environmental conditions along the heavily used beaches of Cape Cod Bay. For example, algal blooms caused by nutrient loading could interfere with feeding activity of the threatened population of right whales in Cape Cod Bay.

Expensive public investment choices regarding ocean waste disposal are driven by ocean circulation models. Having accurate predictions can prevent unnecessary expenditures or avoidable damages to eco-systems or both.

As a result, extensive monitoring efforts are underway to characterize marine environmental conditions in Massachusetts Bay and Cape Cod Bay prior to and after the utilization of the new outfall. This monitoring effort can detect events such as nutrient loadings and algal blooms. However, a significant problem arises in the interpretation of such detections. The exchange of water between Massachusetts Bay and the Gulf of Maine is not well understood; a single buoy now measures currents across a 100 km interface. Therefore it is not possible to say with certainty, for example, that an algal bloom event observed in Cape Cod Bay is due to the outfall or due to advection from the Gulf of Maine.

This situation is not unique to the Massachusetts Bay outfall. Circulation models, on which predictions of discharge dispersion and transport depend, usually require information about currents and winds at the models' open ocean boundaries. When this information is not available, our ability to calibrate the circulation and transport models is compromised, and it becomes difficult to interpret the events we observe. ISOOS data would improve our ability to build realistic circulation models of Massachusetts Bay and similar water bodies.

In many cases, expensive public investment choices regarding ocean waste disposal are driven by the consequences predicted from ocean circulation models. Having accurate predictions can prevent unnecessary expenditures or avoidable damages to eco-systems or both. For these reasons, the informational value of ISOOS data would be high in situations such as this.

Beach Closures

Another direct economic benefit from improved understanding of ocean circulation patterns made possible by ISOOS is in the area of recreational access to the ocean. Millions of Americans use coastal beaches throughout the year as a major source of recreation, and thousands of jobs in almost every coastal state depend on access to safe, clean beaches. Estimates of the value (consumer surplus) of a beach day range from about $5 per person for low-quality beaches to more than $100 per person for desirable destinations (Freeman 1995). Bell and Leeworthy (1990) estimate that 70 million tourist beach days are spent each year in Florida alone. Clearly these estimates point to an enormous overall value of the nation's beaches for recreational activities. But there are threats to these beaches directly connected to the movement of ocean waters. In California and much of the east, for example, combined sewer overflows can temporarily close beaches when high levels of untreated sewage are pumped into the sea following storms. Another threat that exists on all coasts is from oil spills.

Values of a beach day range from about $5 per person to more than $100 for desirable destinations. Seventy million tourist beach days are spent each year in Florida alone… ISOOS should help avoid unnecessary beach closures…making more beach time available for recreation as well as avoidance of losses to businesses.

In each of these cases, a thorough understanding of near-shore ocean circulation is essential to knowing when and where the pollutants will go, and for how long they will degrade beaches. Near-shore circulation is influenced, in turn, by larger currents and weather conditions in the open ocean. In the case of oil spills, deployment of clean up equipment and strategies depends heavily on oceanographic models that also depend on ocean circulation data. All of these applications will benefit from the more comprehensive the data delivered by ISOOS.

ISOOS will not eliminate beach closures. However, its integrated analysis should help agencies avoid unnecessary precautionary beach closures and reduce the duration of closures. The result will be more beach time available for recreation as well as avoidance of losses to businesses dependent on this critical resource.

Additional Benefits from Ocean Data

This section reviews what is known or might plausibly be assumed about a wide variety of other benefits that can be derived from ISOOS data. We divide this section into four subsections, representing types of informational products from which benefits would be derived. These subsections are: short-term weather forecasts, seasonal weather forecasts, marine forecasts and ocean data, and basic research.

Short-term Weather Forecasts

ISOOS data are important inputs to short-term weather forecasts. Weather forecast models rely on current information about parameters such as temperature, barometric pressures, and wind speed. The state of these conditions over the oceans are as important to weather forecasts as that over land, but to date our sampling of conditions at sea is much less complete than our measurement on land. Weather can significantly affect economic values and even endanger human life, and in many situations it is possible to modify actions in response to forecasts to take advantage of favorable weather or reduce the impacts of unfavorable weather. Thus, weather forecasts have economic value.

Storm Forecasts

The value of short-term weather forecasts is perhaps most obvious in the case of forecasts of major storms, such as hurricanes and tornadoes. Storm such as these often do a great deal of damage to property and present serious risks to human life. Improved storm predictions over the last century have reduced the property damage from major storms and dramatically reduced injury and death from such storms.

Short-term weather forecasts also have value in more mundane situations, such as in the management of electric generating capacity.

Electric Power Production

Short-term weather forecasts also have value in more mundane situations, such as in the management of electric generating capacity. In some parts of the United States, short-term weather events can dramatically affect demand for electricity. For example, a severe afternoon rainstorm over Phoenix, Arizona during July or August can reduce peak demand (largely determined by air conditioning) by as much as 30 percent. Because it takes time to switch utility generators to shutdown or standby mode, these large peak demand swings can lead to inefficient use of generating capacity. The cost of this inefficiency has led utilities such as Arizona's Salt River Project to work with forecasters on improved short-term weather warning systems (EPRI 1994). More accurate short-term forecasts enabled by ISOOS observations can help other utilities use their generating capacity more efficiently.

Seasonal Weather Forecasts

In recent years, the National Oceanic and Atmospheric Administration (NOAA) has been able to make reliable forecasts of the longer-term weather phenomenon known as the El Niño Southern Oscillation (ENSO). ENSO has three states, known as El Niño, El Viejo (or La Niña), and Normal. U.S. weather conditions over periods of several months are predictably different depending on which of these states exists. For example, during an El Niño state, winter weather tends to be warm in the Upper Midwest, and wet in the Southeast. NOAA has become proficient at predicting the ENSO state with several months leadtime. Ocean observations, such as temperature and sea surface pressure in the tropical Pacific, play a central role in producing ENSO forecasts. It should be noted, however, that ENSO predictions are not perfect. By some measures, present ENSO prediction is about 70 percent accurate one year in advance. Moreover, the climate conditions associated with a particular ENSO state remain uncertain even if the ENSO state is perfectly predicted. For example, the 1997-'98 El Niño was expected to bring a relatively wet fall and a dry spring to the Tennessee Valley Authority's reservoir recharge areas—but the opposite pattern materialized, in part because of non-typical circulation patterns.

ENSO is important, but it is not the only ocean phenomenon affecting our weather. Northward heat transport in the Atlantic is a unique component of the global climate system. Variability in this transport through variability in cold water convection near Greenland, changes in the Gulf Stream, and fluctuations in the so-called North Atlantic Oscillation create quasi-periodic variations in climate and oceanic conditions. These fluctuations have a periodicity of the order of 10-14 years, and affect terrestrial climate at a continental scale, and also determine fish stock migrations. It is likely that the NAO is responsible for seasonal to inter-annual weather cycles in the eastern US and especially in western Europe. If the ability to make seasonal to inter-annual forecasts based on NAO develops similarly to that based on ENSO, the value of information benefits discussed in the following sections likely will be higher.

Many industrial and recreational activities are affected by the kinds of seasonal to inter-annual fluctuations in the weather that are now being predicted by the ENSO forecasts. Two of these—agriculture and hydroelectric generation—were highlighted above in previous sections. In addition, space heating and cooling requirements depend on outside temperatures. Construction activities are more efficiently carried out when the weather is warmer and dryer. Some kinds of outdoor recreation, such as skiing, may be more enjoyable and/or cheaper to provide when temperature and precipitation patterns are favorable. ENSO phases affect fish productivity, and forecasts of ENSO phases may allow fisheries managers to better manage harvest rates in anticipation of future ENSO phases. Finally, the general public may derive a benefit from seasonal weather predictions by being able to prepare in advance for wet or stormy weather conditions. In the subsections that follow, we describe in qualitative terms how improved ENSO forecasts can be used to advantage in some of these additional activities, and give a sense of the scale of these activities in the U.S. economy. In the few cases where there are relevant quantitative estimates of the value of forecasts, these are included as well. Table 2 contains a summary of this information. The following subsections describe specific activities that will benefit from ISOOS via improved long-range weather forecasts.

Many industrial and recreational activities are affected by the kinds of seasonal to inter-annual fluctuations in the weather that are now being predicted by the ENSO forecasts

Oil and Gas for Space Heating

Space heating requirements change with the outside temperature. Seasonal forecasts of temperature are therefore useful in managing the production and delivery of energy products for heating. There are two activities involved here: managing storage and managing refinery product runs.

Storage in a typical natural gas delivery system makes use of underground sites such as salt domes for large-scale storage. Gas is set aside during the summer months to augment flowing gas provided during the winter heating months. This gas might be drawn down over periods of weeks or months. Once the winter peak demand period has passed, the potential capital gain from storing gas will disappear. As a result, delaying the sale of any gas remaining in storage becomes very expensive, and it makes increasing sense to use this gas. The exact timing of the decision to use remaining stored gas will be driven by the weather forecast for the remainder of the winter.

Storage of fuel oil has traditionally occurred at refineries. However, the amount of such storage capacity has fallen relative to fuel oil use in recent years, due to a dearth of new refinery construction. This is particularly a problem in the fuel oil dependent Northeast region of the United States. In response to the sharp rise in fuel oil prices in the winter of 1999-2000, the President has proposed the creation of a Regional Home Heating Oil Reserve for the Northeast Unite States. When such a reserve becomes operational, seasonal weather forecasts will play a role similar to their role in managing natural gas storage. That is, once the storage capacity is in place, it will normally make sense to fill it completely, prior to the heating season. Then, as the season progresses and nears its end, it will make sense to use any remaining inventory. The timing of the decision to use remaining inventory will be primarily determined by the weather forecast for the remainder of the winter.

There is also a significant degree of flexibility in refinery production of heating fuels and transportation fuels. Typically, refineries in the US increase the fraction of output in the form of heating fuels in the winter, and increase the fraction of transportation fuels in the summer. The output proportions are changed partly by altering the refinery process parameters, and partly by changing the types of crude oils that are used in the refinery. Changes in the output process can typically be made fairly quickly, and thus would not necessarily benefit from seasonal temperature forecasts. Changing the types of crude oils used as input to refineries, however, has a lead-time due to the shipping time required to get crude oil from overseas producers. This implies that there is a value to seasonal temperature forecasts in deciding on the time to shift from production of transportation fuels to heating fuels and back again.

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There are no quantitative estimates of the value of climate forecasts to the energy distribution or refining businesses. However, since these businesses represent large sectors of our economy and the potential economic losses associated with winter shortages are great, the value of information for seasonal forecasts in these industries is likely to be large.

Construction

As noted above, construction projects can be carried out more efficiently when weather conditions are favorable. Improved weather forecast would affect decisions made in construction activities. For example, it may be more efficient to carry a given project through to completion, rather than starting and later suspending work due to unfavorable weather. In some cases, the inefficiency of stopping and restarting may be such that the project is simply put off until some later time when the chance of having to stop is very small. In such cases, a weather forecast that clarified the prospects for being able to carry a project through to completion might affect when the project is started. Thus there is an economic value of better weather information in the construction industry.

Storm Damage Prevention

Anecdotal evidence suggests that decisions that protect property from storm damage can be improved if a reliable long-term weather forecast is available. On the U.S. West Coast, for example, El Niño frequently brings a great increase in winter precipitation. In response to the forecast of an El Niño winter in 1997-1998, both private citizens and local government agencies took actions to prepare for a wet and stormy winter.

Decisions that protect property from storm damage can be improved if a reliable long-term weather forecast is available.

Private property owners did things like repairing or replacing roofs in anticipation of winter storms. This can be viewed as routine maintenance work that is accelerated because there is reason to think that winter storms will be particularly strong. The benefit of such accelerated maintenance is a reduction in the risk or extent of damage to the inside of structures due to leaking roofs during heavy winter storms. Local government agencies took actions to clear stream beds and drainage ditches of accumulated debris. This had the effect of reducing the potential for flooding as a result of heavy rains.

Commercial Fisheries

Like agriculture, segments of the fishing industry can gain by incorporating climate forecasts into management and harvest decisions. For some fish species, such as salmon, recruitment and escapement are influenced by conditions that are directly related to ENSO weather patterns and ocean conditions. Due to the life cycle of such fish, management decisions in one period affect population levels in subsequent periods. In the face of an ENSO forecast 12 to 18 months in advance, managers can increase or decrease harvest levels and the production of hatchery raised fish in anticipation of either favorable or unfavorable recruitment conditions. For example, ENSO forecasts in a small northwestern Coho salmon fishery have been estimated to produce net benefits in excess of $1 million per year, nearly 10 percent of the landed value produced by this fishery (Adams *et al.* 1998). Similarly, because Atlantic fish recruitment may be related to the North Atlantic Oscillation, seasonal forecasts based on the NAO may produce similar benefits in Atlantic fisheries management.

Like agriculture, segments of the fishing industry can gain by incorporating climate forecasts into management and harvest decisions.

Outdoor recreation

The vacation choices of skiers and other outdoor enthusiasts likely would change significantly in response to better information about weather conditions. Given accurate long-term precipitation and temperature forecasts, some skiers would make different choices about where to go for a skiing vacation, or even whether to take a skiing vacation, as opposed to an alternative, such as snorkeling in the Caribbean or touring the restaurants of France. From the point of view of operators of outdoor recreation facilities, revenues and profits would be more variable over time, but would probably be about the same or slightly higher on average.[6] From the point of view of participants in outdoor recreation activities, the overall utility or perceived benefits of participation would be higher. Thus there is economic value in improved weather forecasts for outdoor recreation activities.

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For operators of skiing facilities that make artificial snow, there is a clear economic value of snow forecasts. The largest component of costs for a ski operator is the cost of making artificial snow. Moreover, since it takes time to accumulate sufficient snow for skiing, snow-making is generally started well in advance of the opening of the ski slopes. If there were a reliable forecast of above normal natural snowfall, it would be possible for ski operators to reduce or eliminate snow-making activities, and thereby realize significant cost savings.

Famine and Health

Correlations have been demonstrated between health impacts, disease and famine, and ENSO (Lewis *et al.* 1998; Hales *et al.* 1999; Glantz *et al.* 1997). Climate forecasts provide an opportunity to diminish the effects of climate variability on human health. Glantz notes that through proper planning of agriculture, water management, and health services, the impacts of drought can be diminished. Central to these planning activities are climate forecasts. Further, he notes, USAID is currently using ENSO-based forecasts in their planning activities.

USAID is currently using ENSO-based forecasts in their planning activities.

Marine Forecasts and Ocean Data

Marine weather forecasts, reports on current conditions, and historical statistics are useful in a wide range of economic activities. In a previous section, we highlighted the use of such data in coastal management, specifically, to manage waste disposal activities and beach closures. Here we discuss many more activities where this kind of information is used. These include the maritime transportation industry,

[6] To the extent that better weather information created greater demand for outdoor recreation (because a spoiled vacation is easier to avoid), revenues and profits would be higher.

commercial fishing, offshore energy production, coastal and maritime recreation, the military, marine search and rescue operations, oil spill containment and cleanup, design of ocean structures, and research and monitoring related to global climate change. ISOOS will improve the collection and availability of data and information for all of these uses. An assessment of the costs and benefits of marine data from a Northern European "regional GOOS" (Stel and Mannix 1997) considered many of these same uses, and estimated annual benefits in the 100s of million of dollars—perhaps an order of magnitude greater than annual costs.

Maritime Transportation

At least half of all commercial ocean transits today take advantage of weather-based vessel routing services, saving on the order of $300 million in transportation costs annually.

The maritime transportation industry derives benefits from a number of marine weather forecasts and reports on current conditions. Among these are storm forecasts, reports on currents and wave conditions, reports on water levels in ports, and reports on visibility.

Storm forecasts are of value since they may allow a vessel operator to alter course or speed to reduce the risks of storms to both life and property.

There is a tradeoff between vessel speed and wear and tear on the vessel. Knowing current and wave conditions allows vessel operators to achieve the best balance between speed and wear and tear.

Knowledge of the location and speed of ocean currents, notably the Gulf Stream, is valuable information because it allows vessels to choose routes that take advantage of these currents. Picking a route from the United States to Europe that takes advantage of the Gulf Stream, for example, can reduce the transit time by several hours.

At least half of all commercial ocean transits today take advantage of weather-based vessel routing services. These services rely on wind and wave models that are calibrated with sea surface pressure and other observations. Kite-Powell (2000) has estimated that these services now save on the order of $300 million in transportation costs annually. These savings could be increased considerably with better real-time information about ocean wind, waves, and currents.

Most major U.S. ports are depth-constrained. Vessel operators balance the risk of grounding against the lost revenue associated with each inch of draft that is not utilized because of this constraint. Precise real-time and forecast water level information is therefore of considerable value to commercial shipping in some ports (WHOI 1993; Kite-Powell *et al.* 1994).

Visibility problems such as coastal fog require a vessel to enter or leave ports more slowly. Shipping companies, particularly those operating on regularly scheduled liner routes, use forecasts of reduced visibility conditions to determine vessel speed during a transit. Vessel speed directly influences fuel expenses; and course alterations are expensive even if they do not involve speed increases. Delayed arrivals are also expensive because of commitments to longshore crews. Having a forecast of coastal visibility conditions may allow a vessel operator to modify the vessel's transit schedule to minimize the costs of visibility induced delays (WHOI 1993; Kite-Powell *et al.* 1994).

To the extent that the international community is determined to secure a sustainable future for commercial fisheries, it will need a better understanding of the ocean conditions

Commercial Fishing

Water temperature and streamflow affect fish abundance and reproductive behavior. Fisheries managers can use better information about marine conditions and precipitation in coastal watersheds to develop better estimates of stock size and recruitment. This provides managers and fishers greater certainty about sustainable harvest levels, and enables them to use wild capture fish stocks more efficiently.

Fishing vessel operators could benefit from improved wind/wave forecasts to make go/no go decisions on fishing trips and reduce losses of vessels and lives due to poor weather. In addition, commercial fishers can use three-dimensional water temperature information to optimize their fishing effort and reduce fishing costs (WHOI 1993).

We note that efficient use of the world's fisheries resources requires more than good information about fish stocks and marine conditions—it also requires good fisheries management. Marine fisheries play an important role in supplying protein for human nutrition, and have the potential to play an even more significant role in the future. To the extent that the international community is determined to secure a sustainable future for commercial fisheries, it will need a better understanding of the ocean conditions under which fish reproduce and survive and, importantly, a better monitoring in support of associated national and international regulation. ISOOS outputs will play an important role in this effort.

Offshore Energy Production

Hurricanes pose risks to life and property for offshore oil and gas operations. There are high costs both of failing to anticipate a hurricane that occurs and of preparing for a hurricane that fails to occur. For these reasons, accurate forecasts of hurricanes and their expected tracks are valuable to offshore oil and gas platform operators.

Loop Current eddies in the Gulf of Mexico are also of concern to offshore oil and gas operators, because they can cause significant disruptions of exploratory drilling operations. Loop Current eddies are powerful and deep localized currents that can damage drill strings deployed below drilling vessels. Forecasts of Loop Current eddies have value to offshore oil and gas operators because they make it possible to set more efficient drilling schedules (WHOI 1993).

Forecasts of weather and conditions are valuable to offshore operators to avoid either risks to equipment or expensive interruptions of operations.

Other kinds of offshore operations are sensitive to weather and/or surface and subsurface ocean conditions. These include operations of heavy lifts, pipe-laying, pipe-trenching, tie-ins, remotely operated vehicle (ROV) operations, and deep-water pile driving. For example, crane barges capable of lifting 10,000 tons at a single lift are required regularly to lift the deck module structures onto the legs or "jackets" of oil platforms after they have been installed. These operations are highly sensitive to wind and waves, and need forecasts of 10 to 20 days if possible. Pipelaying barges are required to lay many miles of steel and concrete pipes in water depths of up to 1000 feet. The pipe hangs from the stern of the barge during laying, and the operation is sensitive to sub-surface currents, surface waves, winds. ROVs fitted with hydraulic power tools are used for many operations on deep water oil and gas production. These machines operate with long cables and power lines exposed in the water, and are sensitive to current profiles and to wind-wave forces on surface support vessels.

Forecasts of weather and conditions are valuable to offshore operators because they make it possible to schedule these kinds of operations to avoid either risks to equipment or expensive interruptions of operations. As offshore operations move into deeper waters, knowledge and forecasts of sub-surface conditions are becoming increasingly important.

Military

Naval operations and training exercises rely on extensive weather and marine condition forecasts. Uses include vessel routing and tactical planning. The U.S. Navy maintains its own observation and modeling efforts to support its forces in the field (see WHOI 1993 and Kite-Powell *et al.* 1994). By coordinating ISOOS activi-

The benefits of forecasts and reports for these activities include reduced risk to human life, reduced risk of property loss, and increased enjoyment from ocean related recreation.

This information can lead to better success in locating survivors, and thereby improve their chances of rescue.

ties with the Navy's efforts, military forecasting needs could be better served and costs could likely be reduced. U.S. Navy experience with improved modeling and forecasting services suggests that the Navy's own investments in improved storm warning systems and forecasts for vessel routing have proven highly cost-effective (WHOI 1993).

Marine Recreation

Marine forecasts and conditions reports are used in planning a wide variety of recreational activities associated with the coast and the ocean. These include recreational boating, recreational fishing, surfing, diving, swimming, and general beach activities. The benefits of forecasts and reports for these activities include reduced risk to human life, reduced risk of property loss, and increased enjoyment from ocean related recreation.

Some preliminary work has been done to estimate the value of improved forecasts for recreational boating (Kite-Powell *et al.* 1994). This work suggests that annual benefits to recreational boaters (*e.g.,* better trip planning with marine conditions forecasts) would be in the tens of millions of dollars annually.

Search and Rescue

The U.S. Coast Guard is responsible for search and rescue (SAR) operations when commercial or recreational vessels encounter difficulties in U.S. waters. A large part of the challenge in many SAR cases is locating survivors of an accident. The Coast Guard could use improved ocean observation data to construct better models of currents and other factors that determine the drift of life rafts or persons in the water. This information can lead to better success in locating survivors, and thereby improve their chances of rescue. Even small improvements (order of one percent) in search efficiency could enhance search and rescue performance sufficiently to generate life and property savings in excess of $100 million per year (Kite-Powell *et al.* 1994).[7]

Oil Spill Containment and Cleanup

A related activity is responding to marine accidents that create spills of oil or oil refined oil products; the accident involving the Exxon Valdez is a dramatic example. It is important in such situations to be able to predict accurately the path

[7]The study assumes a value per human life of $4 million.

that the spilled oil or refined product will follow. If this can be predicted accurately, the limited supply of barriers and cleaning capacity can be dispatched to the right places to minimize the damage resulting from the spill. Total damage from the Exxon Valdez spill has been estimated to be in excess of several billion dollars, implying that the potential value of information here could be very high.

ISOOS data will advance our understanding of fundamental processes relevant to global climate change. A great deal of economic value is at stake in this process, and information that improves decisions will have high value.

Ocean Structure Design

Various governmental authorities are responsible for licensing or certifying structures and vessels designed to be used on, in, or near the oceans. In setting appropriate design specifications, these authorities use historical statistics on ocean conditions, such are waves, winds, currents, temperature, etc. These historical statistics are used as a proxy for the conditions that are likely to be encountered in the future, and design specifications are set to reduce the risks of accidents to appropriate levels.

A great deal of expensive capital investment is guided by these design specifications, and the cost of being wrong about these specifications is high. If specifications are too stringent, capital costs are higher than need be, while if specifications are too lenient, risks will be too high. Thus, there is likely to be significant informational value in these historical statistics.

Global Climate Change

Global climate change is an important issue. The recently signed (but not yet ratified) Kyoto protocol proposes limits on CO_2 emissions that could have high economic costs.[8] Obviously, there would be significant benefits to making the best possible future decisions about limiting emissions.

ISOOS data will advance our understanding of fundamental processes relevant to global climate change. These processes include (1) heat transport and fluxes between the ocean and atmosphere, (2) heat transport within the oceans, particularly by ocean currents from the equator to high latitudes, and (3) the removal of carbon from the atmosphere by oceanic processes. In addition, some ISOOS data, such as sea level measurements, would directly monitor the effects of climate change and allow us to better predict the magnitude of these effects.

[8]Weyant and Hill (1999) present an overview of estimates of the costs of implementing the emission limits called for in the Kyoto protocol.

Information obtained from oceanic research will inform the policy making process. Because measures to reduce emissions of carbon dioxide are very expensive,[9] a great deal of economic value is at stake in this process, and information that improves decisions will have high value.

A few efforts have been undertaken to place a value on improved global climate change information. One study considered a hypothetical situation in which new climate change information would lead us to adopt one of three possible policies: no CO_2 emissions control, limiting CO_2 emissions at 20 percent below the 1990 level, and limiting CO_2 emission at 50 percent below the 1990 level. Two scenarios were then considered: learn the correct emission policy now, or learn it 20 years in the future. The worldwide benefits of learning the policy now were estimated at up to $80 billion, depending on the prior probabilities of each of the policies being the correct one (Manne and Richels, 1992). One might speculate that 25 percent of this, or up to $20 billion, would be the United States' share of this value of information, since the U.S. economy is about a quarter of the world economy.

Another study explored the value of immediate vs. 40 year delayed resolution of uncertainty about a few key parameters governing the theoretically optimal policy for controlling CO_2 emissions. For the world as a whole, this study found values of immediate uncertainty resolution in the neighborhood of $20-30 billion for each of two key uncertain parameters, and about $50 billion for both parameters together (Peck and Teisberg, 1993).[10] Again, the U.S. share of this $50 billion might be $12.5 billion. While the two key uncertain parameters analyzed in this study were unrelated to the role of the oceans in the climate change process, these results nevertheless suggest that large values of information are possible in the context of the global warming issue.

The same study also reported that the values of early uncertainty resolution go up by one to three orders of magnitude if early resolution of uncertainty improves the rationality of policy decisions. For this analysis, it was assumed that arbitrary policies would be adopted under uncertainty, while optimal policies would be

[9]*Ibid.*

[10]The likely reason these numbers are lower than the Manne-Richels numbers is that the range of optimal policies implied by the assumed parameter uncertainty is less than the range of possible policies considered in the Manne-Richels study.

[11]These calculations consider complete and immediate resolution of all uncertainty, and they assume uncertainty only with regard to one or two of the most critical parameters influencing optimal policy.

adopted with uncertainty resolution. Two alternative arbitrary (but not implausible) policies were assumed to be adopted under uncertainty; these were no control and limiting emissions at the 1990 level. The Kyoto protocol, for example, envisions developed countries limiting emissions at roughly 92 percent of 1990 levels. While these results are unrealistic in some ways,[11] they nevertheless suggest that there is very high value to information that improves the rationality of policy decisions.

Some experts have speculated that global climate change may cause the oceans to spawn more frequent extreme events, e.g. strong ENSO phases that influence economic activity on the land (Timmermann *et al.* 1999). If so, the benefits to accurate ENSO forecasts would rise. Also, there are substantial social costs of extreme events that monitoring and possible climate change mitigation might help avoid (Chen *et al.* 2000). ISOOS data would aid in both the monitoring and forecast formation processes.

Some experts also worry that global climate change could interfere with the normal functioning of the Gulf Stream and possibly cause it to shut down entirely (IPCC 1995; Cline 1992). The Gulf Stream is an ocean current that flows from the equatorial regions near the Americas north and east to northern Europe. The Gulf Stream is important in many ways, but its greatest importance is that it warms the climate of Europe. Some of the data produced by ISOOS would relate to the functioning of the Gulf Stream. It is possible that this data could at some future date warn of a possible shutdown of the Gulf Stream. It is unknown whether any actions could be taken in response to such a warning, but if actions were possible, the value of that information would be very high.

Benefits from Basic Research

Some of the data and information that would be produced by ISOOS would contribute to research that is appropriately thought of as "basic" in nature. "Basic" means that there are no obvious applications of the research at the time it is initiated. Basic research is difficult to value using the techniques discussed above, because the ultimate use of such data is hard to predict.

This indirect and long-term nature of the relationship between the government's investment in research has long been recognized as a critical factor in economic growth.

Public investment in basic scientific research has been a cornerstone of Federal science and technology policy since World War II. Every President and Congress since then has recognized of the need for this public investment in basic research. An important example of basic research is the early public support for semiconductor research, largely motivated by military applications. This has ultimately led to a myriad of products and activities that underlie the "information economy," which has created enormous income and wealth for the United States. Not all basic research can be expected to yield such returns, but it only takes an occasional success like this to more than compensate for the other projects in the research portfolio may not pay off, or that pay off only modestly. The role of public investment has been critical because the pay off in commercial products and services often lags the initial findings by many years, and because the links are often indirect as many different discoveries come together to create new products. These circumstances make it difficult for private investors to capture the full benefits of basic research, which in turn means that basic research has the character of a public good (see the section, *Economic Considerations in Valuing ISOOS*).

This indirect and long-term nature of the relationship between the government's investment in research has long been recognized as a critical factor in economic growth, but measuring it has been difficult. Nonetheless, a number of studies have attempted to measure the contribution of "technical progress" to economic growth. "Technical progress" combines the accumulation of basic knowledge (without any immediate application) with applied research and development (transforming basic knowledge into a myriad of goods and services provided by both the public and private sectors). The idea of "technical progress" combines both basic and applied research because of the extremely fuzzy line between the two.

Estimates of the long term contribution to U.S. economic growth from technical progress have varied depending on the time period chosen and the choice of statistic to measure economic growth. But the results have been quite significant. Mean estimates range from a low of 25 percent of economic growth to a high of 50 percent, depending on whether quantity of goods and services alone is measured (the low estimate) or improved quality is also taken into account. Thus technical progress can be seen as perhaps the single largest contributor to long term national economic success (Boskin and Lau 1996).

ISOOS should be seen as part of a long line of Federal activities that have increased the stock of basic knowledge about the world and which have in turn contributed greatly to an improved standard of living for Americans.

Clearly these figures are aggregates across the whole economy, and no such claims can be made for ISOOS alone. What is interesting, however, is that the contribution of technical progress is substantially higher when the “quality” of goods and services is measured. This is important because ISOOS will not greatly expand the quantity of goods and services available in the U.S. economy (though some new businesses may be started to take advantage of the information much like private weather forecasters exist to add value to the National Weather Service data). Rather, ISOOS will primarily contribute to the improved quality of many existing services, including longer time horizons, better accuracy, and public and private decision making that avoids unnecessary waste of resources.

Thus, ISOOS should be seen as part of a long line of Federal activities that have increased the stock of basic knowledge about the world and which have in turn contributed greatly to an improved standard of living for Americans and to a healthy economy on which that standard of living depends.

Ongoing and Future Research

As other parts of this paper suggest, we have a fairly good understanding of the links between the data to be produced by ISOOS, the research and informational products that would be supported by this data, and the final applications and potential benefits to be expected from these products. Still, we are not in a position to produce a definitive cost-benefit ratio or net benefits number for ISOOS. Table [1] roughly illustrates the present state of our knowledge about the benefits derived from various forecasts. While we believe that the weight of the evidence supports a conclusion that the economic benefits of ISOOS will exceed the costs, we are unable to quantify the magnitude of these benefits precisely at this time.

To assure that the investment in ISOOS pays off as expected, we recommend that as part of the ISOOS funding, a portion be set aside for monitoring and evaluation of the economic benefits of the project. Again as noted elsewhere, many of these will only become apparent over years or decades. But an understanding of the benefits of some of the short-term effects such as improved understanding of ocean characteristics for weather or mid-range climate forecasts should become apparent within five years of full deployment of the system.

The results of this effort will assure a much more complete understanding of the relationship between economic costs and benefits.

Ongoing evaluation of the economic benefits of ISOOS will require modest expenditures to increase our understanding of the relationship between the ocean and the creation of economic value and of the changes in information and activities that result from the ISOOS. The results of this effort will assure that future modifications to the ISOOS system, which will inevitably be needed as we learn more about the ocean from the first generation system, are considered with a much more complete understanding of the relationship between economic costs and benefits.

Some work is already underway to further our understanding of the economics of improved ocean observation and resulting nowcasts and forecasts. For example:

- **Improved Satellite Images:** Research is underway, funded by NOAA, to quantify benefits from improved polar satellite observation for use in ship routing, harmful algal bloom tracking, and aircraft routing

- **Economic Benefits of Improving Weather Forecasts:** Research is underway in NOAA to estimate the economic value of improved weather forecasts to U.S. households from investments in improved satellite, ocean, and *in situ* observing systems.
- **National Ocean Economics Project:** This project, funded in part by NOAA, is developing updated and considerably expanded information on the role of the ocean in the U.S. economy through estimation of an "ocean gross domestic product" and related economic values.
- **European activities:** EuroGOOS has a permanent Economics Working Group, which is preparing a multi-national study of the value of maritime industries and services across Europe. The industry directorate of the European Commissions (DG3) has already commissioned a study of the economic value of the marine heavy industries and related supporting technologies. EuroGOOS has conducted surveys of data and data product requirements, and related them to industrial sectors, service organizations, and government and research users. EuroGOOS has also studied the relationships between the different types of benefits, and the delay in payback, so as to create a strategy of short-term, medium-term, and long-term investment and acquisition of benefits.

Conclusions

We have noted how ocean data collection in the past has been undertaken on an ad hoc basis. Nevertheless, there is evidence that the information generated from such data has great value. In cases where formal value of information estimates are available, benefits are estimated to be in the hundreds of millions of dollars. In other cases where formal estimates do not exist, there is reason to believe that substantial additional unmeasured benefits exist.

ISOOS would broaden and systematize the collection of ocean data. It is anticipated that such integrated data collection would generate additional benefits that are not available under the current regime. Since large economic benefits are already derived from ocean data, it is a reasonable to expect that the benefits from ISOOS would be very substantial, and comfortably in excess of the expected costs of implementing such a system.

As we have also noted, there are sound reasons why the economic benefits expected from ISOOS are not likely to be realized without public sponsorship of the system. First, ISOOS generates network externalities. Second, uncertainty about benefits acts as an impediment to private negotiations that might otherwise internalize the network externalities through some kind of private cost sharing agreement. Third, in certain respects the information that ISOOS would provide has the character of a public good. For all of these reasons, it makes sense that public funding should be used to provide the basic data collection and verification operations envisioned in ISOOS.

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Appendix: ISOOS Components

NOPP's (1999) plan for implementing ISOOS calls for three dominant courses of action:

- sustaining existing (and new) ocean observations,
- integrating existing (and new) ocean observations, and
- adapting the system to meet evolving needs and utilize new technologies.

NOPP's plan includes specific recommendations and action items covering these topics:

- infrastructure
  - ◆ networks
  - ◆ data management systems
  - ◆ GIS interfaces
- observation of surface fields and fluxes
  - ◆ sea surface temperature
  - ◆ surface winds
  - ◆ surface ecosystem information
  - ◆ sea level height on
  - ◆ long time series stations for full water column sampling
  - ◆ long-term changes in sea level
- coastal ocean
  - ◆ inputs of freshwater, sediments, nutrients, and contaminants
  - ◆ marine meteorological forecasts and circulation models
  - ◆ "coastal index sites" for environmental quality changes
  - ◆ measurement/nowcast/forecast of water level, surface waves, and currents
  - ◆ documentation of changes in water depth and shoreline topography
  - ◆ integration of distinct sea level observing systems
  - ◆ coastal data and information management system implementation
  - ◆ transitioning from pilot stage to operational systems
  - ◆ long-term financial support
  - ◆ guidance and oversight
  - ◆ ongoing strategic planning
  - ◆ continuing review process
  - ◆ resources for rapid tactical evaluation to ensure data quality
  - ◆ Federal/academic/private sector partnership

Table 1: Taxonomy of Forecasts
Shading indicates useful forecasts. Symbols indicate state of benefits assessment:
Q = qualitative only, $? = preliminary numbers, $$$ = solid numbers, W = work underway.

Economic Activity	***nowcast (current conditions)***	***marine weather, water temp., etc. (hours – days)***	***seasonal/ interannual***	***decadal***	***marine hazards (HABs)***	***severe weather (hurricanes)***
Construction			Q			
Recreation	$?	$?	Q		$?, W	Q
Crop agriculture			$$$			
Military	$?	$?				Q
Oil and gas distribution			Q			
Maritime transportation	$?, W	$?, W				
Storm damage mitigation and repair			Q			
Offshore energy		Q				Q
Fisheries	Q		$?		$?, W	
Marine search and rescue (SAR)	$?					
Marine water quality management	Q	Q			$?, W	Q
Freshwater supply management			Q			

Table 2: Economic Activities and the Use and Value of Forecasts

Economic Activity	Column 1 *economic scale of activity*	Column 2 *effect of weather fluctuations*	Column 3 *how forecasts can be used*	Column 4 *effects of the 1997/98 ENSO event*	Column 5 *estimates of forecast value (perfect forecast)*
Construction	$528 billion (1992 construction industries)	temperature and precipitation affect whether construction can proceed	construction managers can better schedule projects	increased seasonal home construction in mid-Atlantic region; more working days for carpenters, painters, etc.	?
Recreation	$100 billion (1992 hotels and recreational amusement centers) $10 billion (1991 rec. boating and fishing expenditures)	temperature and snowfall affect winter sports conditions; rainfall affects other outdoor recreation; severe weather causes accidents at sea and in marinas	vacationers can improve their vacation experience by better planning their travel and sports activities; decisions about going to sea or securing marinas are based on forecasts	better than average recreational fishing in California, Florida, mid-Atlantic states	$10s of millions/year from improved recreational fishing and boating planning and safety
Crop agriculture	$109 billion (1996 cash receipts, all U.S.)	temperature and rainfall affect crop yields	farmers can select crop varieties appropriate to expected temperature and rainfall conditions; distributors can reduce commodity storage if uncertainty about future yields is reduced	$3 billion losses to producers and consumers	$300 million/year for U.S. agriculture $300 million/year for corn storage industry
Military	$87 billion (2000 budget for Navy and Marines)	weather and marine conditions affect military operations	improved safety and efficiency of military operations	?	?
Oil and gas distribution	$76 billion (1992 natural gas production and distribution) $7 billion (residential and commercial heating gas and fuel oil, average)	temperature affects demand for heating fuels	energy suppliers can adjust fuel stores and better time drawdown of stored fuel	$2 billion reduced expenditures for heating fuels due to mild winter	?

Maritime transportation	$25 billion (1987 revenues)	visibility, wind, and water levels affect ships' schedules	better marine conditions forecasts lead to better routing and scheduling	---	<$10 million/year from improved water level forecasts in ports
Storm damage mitigation and repair	$16.7 billion (1992 value of roofing/siding construction work)	storms (wind and precipitation) cause damage to buildings and other infrastructure	homeowners can take measures to minimize storm damage (preemptive repairs); municipalities can prepare for possible floods (clearing drainage canals, etc.)	$500 million in property damage in California $275 million FEMA obligations for storm and flooding damage sales of roofing materials etc. up 20% in California	?
Offshore energy	$16.4 billion (1987 revenues)	hurricanes and strong currents affect operations	improved storm and current predictions can enhance safety and efficiency	---	?
Fisheries	$3.5 billion (1996 landings, all U.S.)	water temperature and streamflow affect fish abundance and reproductive behavior	fishery managers can adjust harvesting to ensure adequate spawning; fishers can use wind and temperature forecasts to improve safety and efficiency	decreased output of fishmeal in South America	$1 million/year for one northwestern coho salmon fishery
Marine search and rescue (SAR)	$700 million in property saved by USCG SAR per year (1993)	wind/waves, currents, and visibility affect SAR operations	better current models can target SAR efforts more effectively	---	>$100 million/year from 1% improvement in search success
Marine water quality management	?	coastal water quality affects recreational and other marine resources	improved information about water quality will enable coastal managers to make better decisions	?	?
Freshwater supply management	?	precipitation affects the amount of water entering reservoirs and the demand for irrigation	water supply managers can improve reservoir management by anticipating future inflows	fall precipitation was late, but spring flows tracked forecast	?